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Headwinds – a story about wind energy

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UNIVERSITY OF THE PACIFIC

Headwinds-
a story about wind energy

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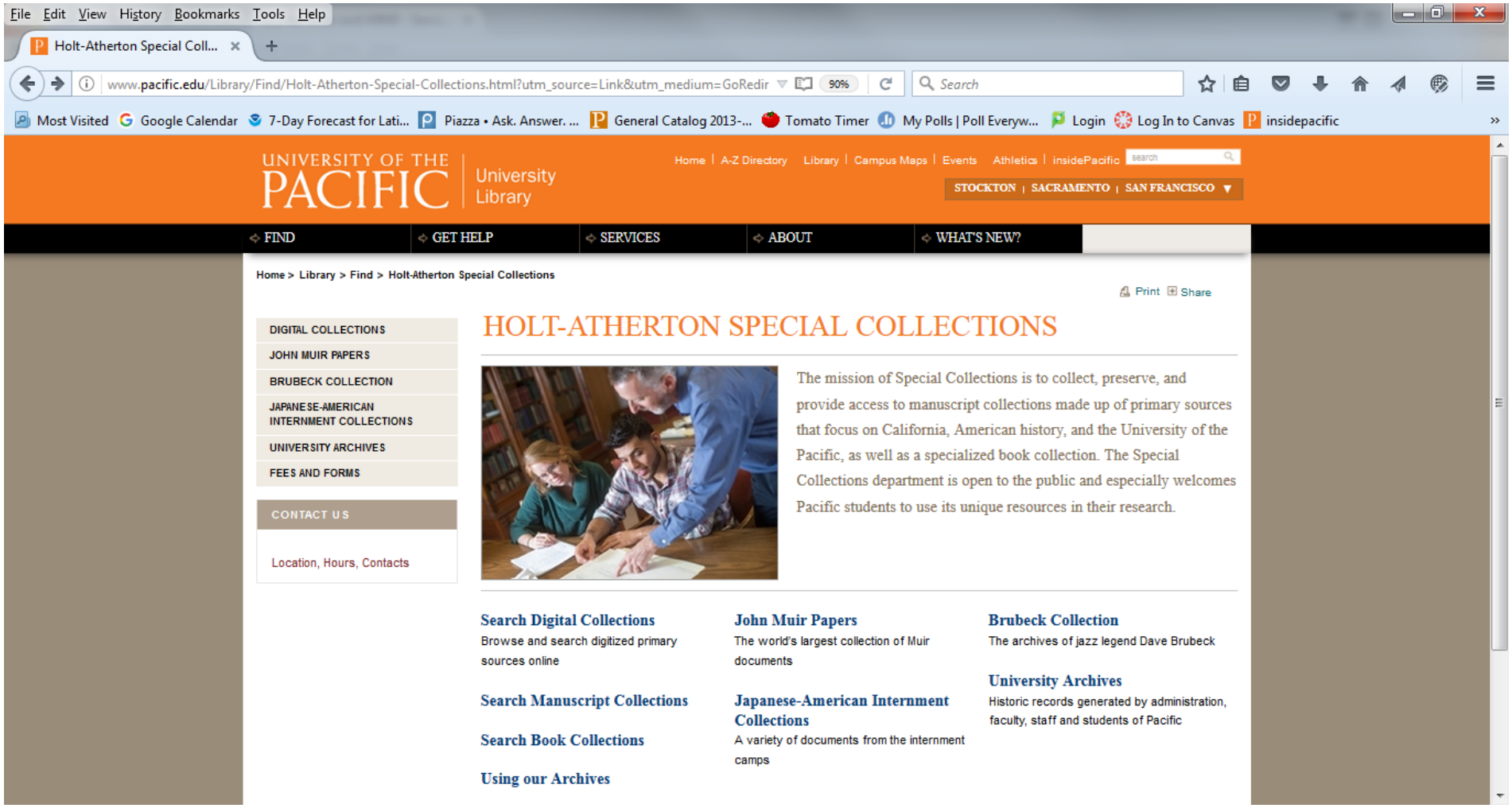
Mechanical Engineering Department

Muir Collection at Pacific



Muir and the wind

Courtesy of TripAdvisor

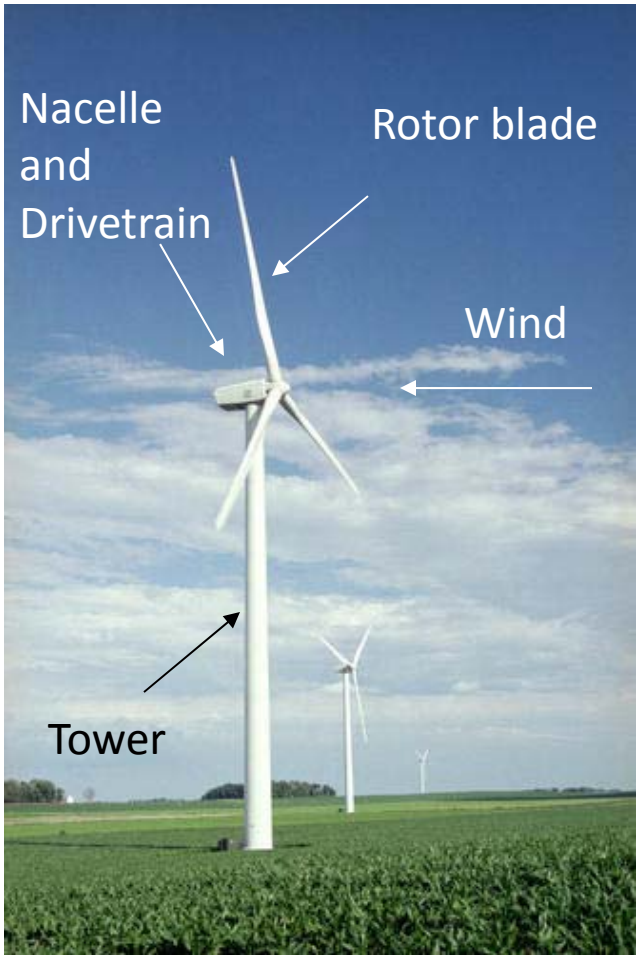
- "their written language is too difficult for human minds"
- "The sky, too, was changed, and I could detect strange sounds in the winds." *A Thousand Mile Walk to the Gulf*

Outline

- The present
- First generation
- Second generation
- Third generation
- The future

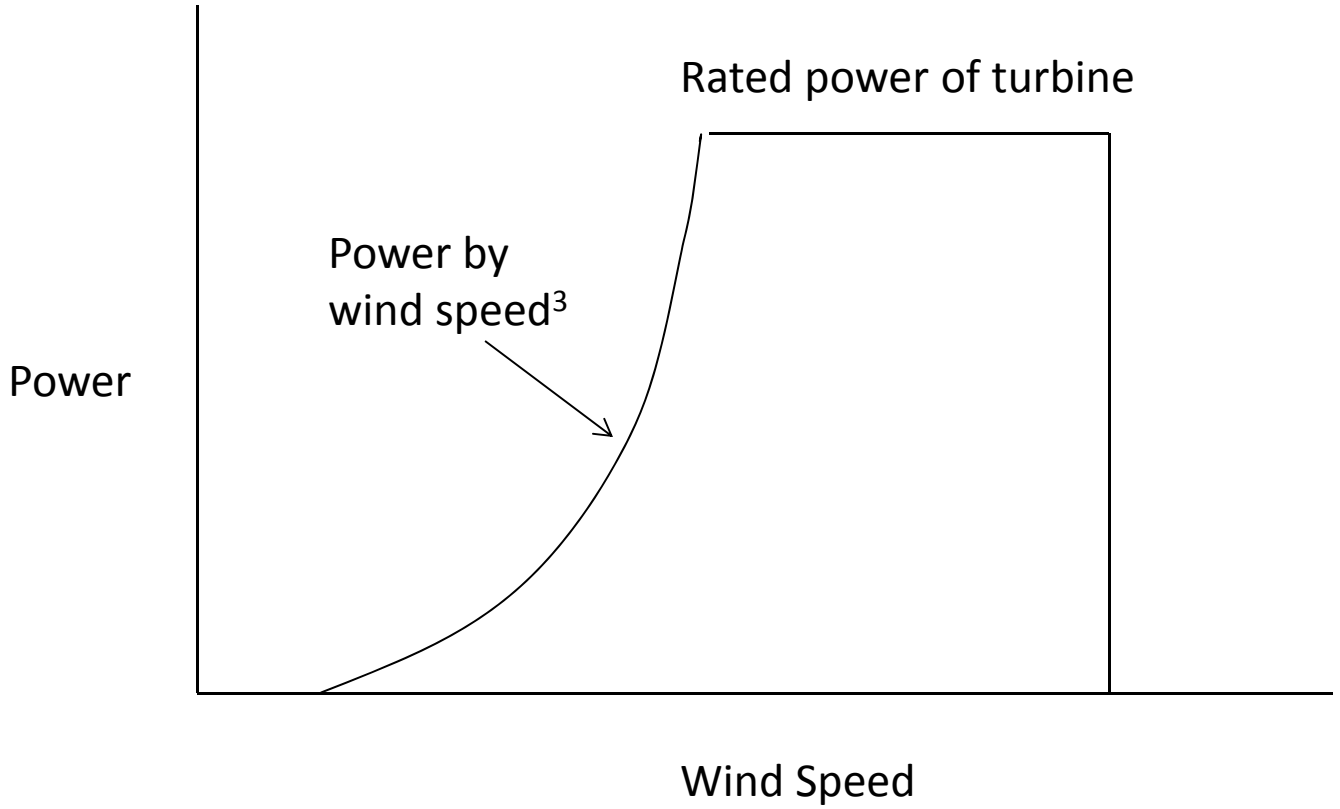
THE PRESENT

The Modern Wind Turbine



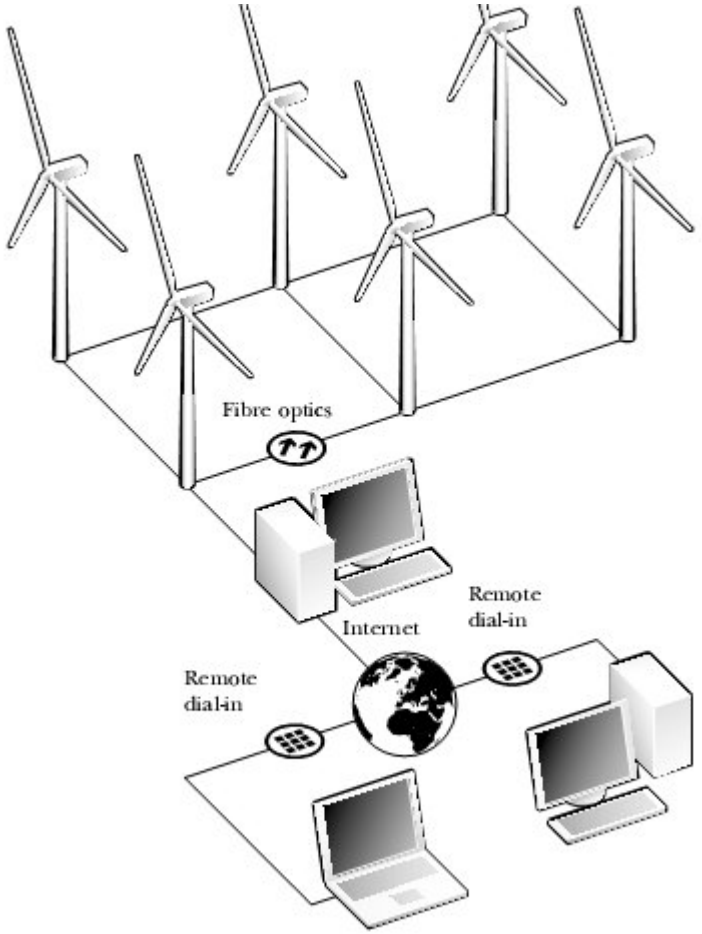
GE 1.5 MW NREL Photo

The Power Curve



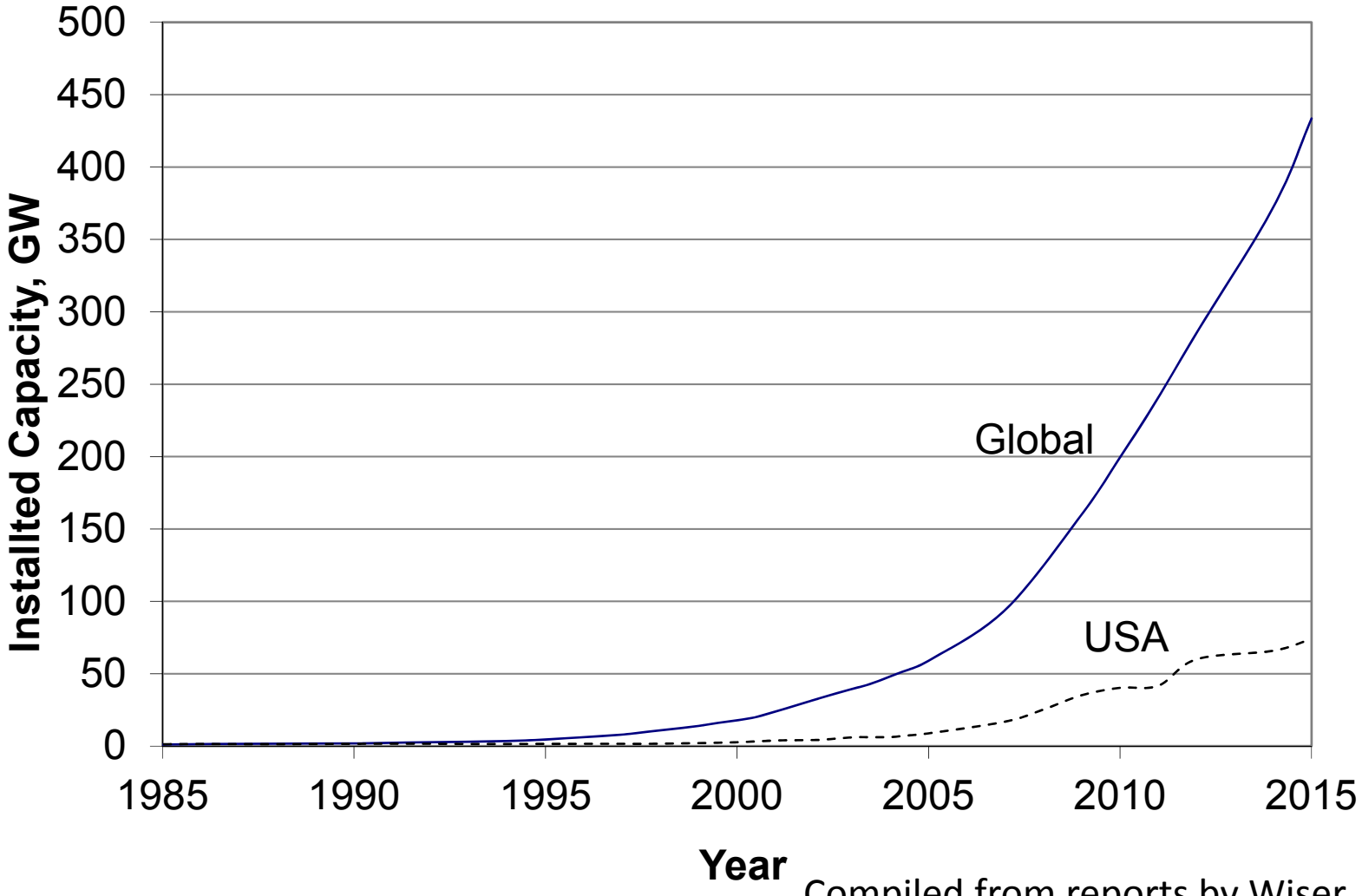
Control of wind energy

- Individual automatic control
- Farm (wind plant) control
- World wide control by manufacturer/owners



Vestas

Growth of Wind Energy



Compiled from reports by Wiser, LBNL

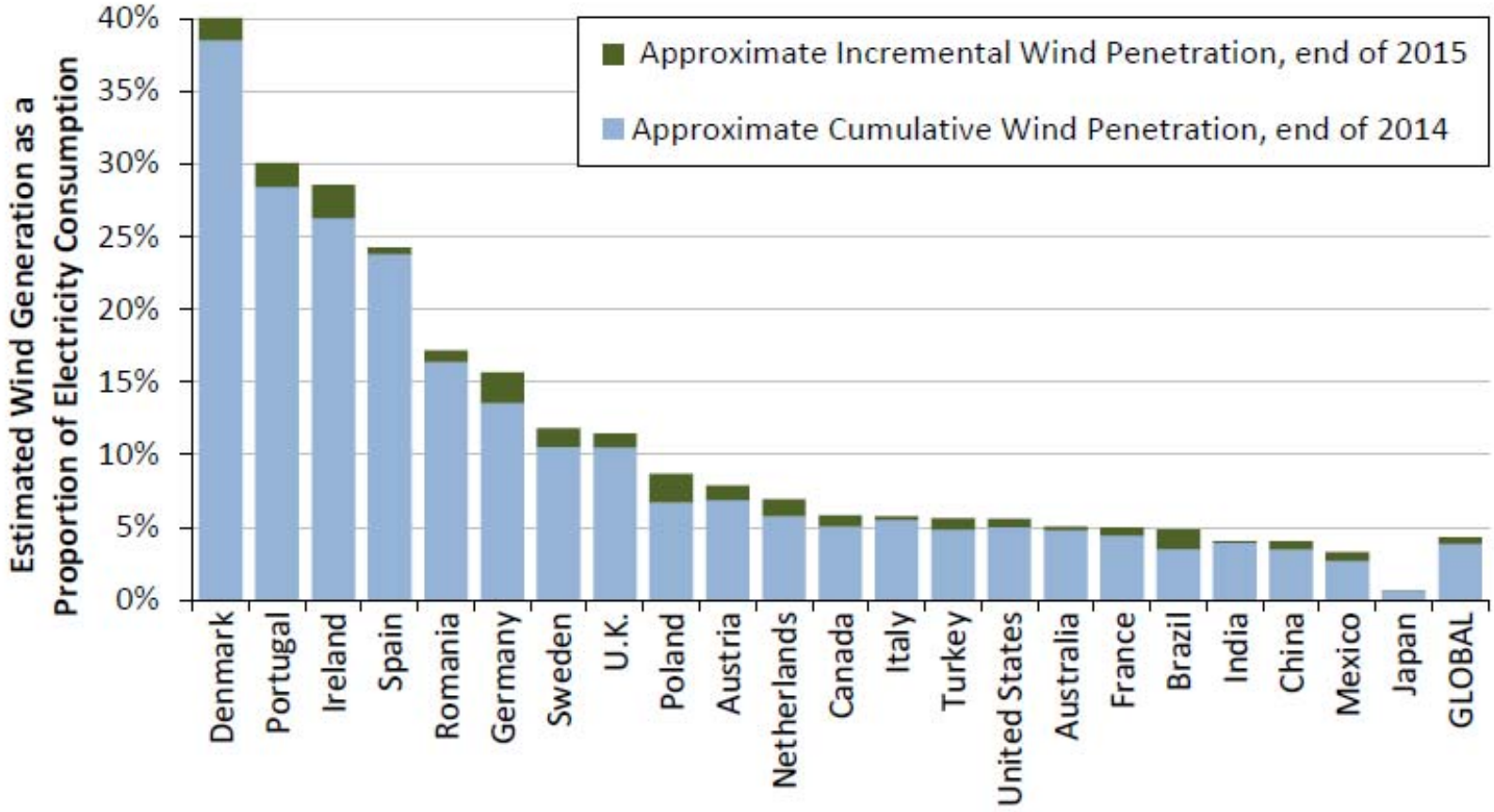
Worldwide capacity

Annual Capacity (2015, MW)		Cumulative Capacity (end of 2015, MW)	
China	30,293	China	145,053
United States	**8,598**	**United States**	**73,992**
Germany	6,013	Germany	44,986
Brazil	2,754	India	25,352
India	2,623	Spain	22,665
Canada	1,506	United Kingdom	13,388
Poland	1,266	Canada	11,190
France	1,073	France	10,243
United Kingdom	975	Brazil	9,346
Turkey	956	Italy	8,851
Rest of World	7,078	*Rest of World*	68,464
TOTAL	**63,135**	**TOTAL**	**433,530**

Source: Navigant; AWEA project database for U.S. capacity

Wiser 2016

How much energy is from wind?



Source: Berkeley Lab estimates based on data from Navigant, EIA, and elsewhere

Wiser 2016

U.S. Wind Energy

Installed Capacity (MW)				Percentage of In-State Generation	
Annual (2015)		Cumulative (end of 2015)		Actual (2015)*	
Texas	3,615	Texas	17,711	Iowa	31.3%
Oklahoma	1,402	Iowa	6,209	South Dakota	25.5%
Kansas	799	California	5,662	Kansas	23.9%
Iowa	524	Oklahoma	5,184	Oklahoma	18.4%
Colorado	399	Illinois	3,842	North Dakota	17.7%
Illinois	274	Kansas	3,764	Minnesota	17.0%
New Mexico	268	Minnesota	3,235	Idaho	16.2%
North Dakota	258	Oregon	3,153	Vermont	15.4%
Minnesota	200	Washington	3,075	Colorado	14.2%
California	194	Colorado	2,965	Oregon	11.3%
South Dakota	175	North Dakota	2,143	Maine	10.5%
Maine	173	Indiana	1,895	Texas	10.0%
Indiana	150	New York	1,749	Nebraska	8.0%
Nebraska	80	Michigan	1,531	Wyoming	7.7%
Arizona	30	Wyoming	1,410	Montana	6.6%
Maryland	30	Pennsylvania	1,340	Washington	6.5%
New Hampshire	14	New Mexico	1,080	New Mexico	6.3%
Ohio	8	South Dakota	977	California	6.2%
Connecticut	5	Idaho	973	Hawaii	6.1%
New York	1	Nebraska	890	Illinois	5.5%
Rest of U.S.	0	*Rest of U.S.*	5,203	*Rest of U.S.*	1.0%
TOTAL	**8,598**	**TOTAL**	**73,992**	**TOTAL**	**4.7%**

* Based on 2015 wind and total generation by state from EIA's *Electric Power Monthly*.

Source: AWEA project database, EIA

Wiser 2016

California Wind Energy

2015- 5.7 GW
8.2% of total energy
(includes imports)

70 GW total generating capacity

How efficient is wind energy

- pollev.com/purlwind

FIRST GENERATION

In the Beginning

Energy crises of the 1970s

- 1973 Arab OPEC Embargo
- 1979 Iranian Revolution
- Dependence of energy supply on foreign imports

Remember when?

No cutting please

Department of Energy (DOE) programs

Boeing MOD-2
NASA Photo

- Late 70s early 80s
- Large investment with NASA in aerospace corporate research
- GE, Boeing, Hamilton Standard
- MOD series turbines

Small turbines

- 25 to100 kW machines
- Univ. of Mass. Wind Furnace
  - Eventually becomes Kenetech Windpower
- Danish firms
  - Vestas, Noordtank, Micon
- Dominate CA wind energy in 80's and 90's

Kenetech turbines- FPL photo

Vestas- Tehachapi CA

My path to wind energy

- Childhood
  - Astronaut!
- Nixon/Carter Years
  - Energy crises
- High school
  - Application to military academies
  - California universities
- Undergraduate
  - Cal Poly – Fall 1984
  - Reagan years

Skylab 4, 1973
NASA Photo

Formative college years

- PG&E internship 1986
- Human-powered helicopter 1985-1989
- Developed interest in low-Reynolds number flows

Boeing MOD-2
NASA Photo

Cal Poly DaVinci III, 1989
William Patterson Photo

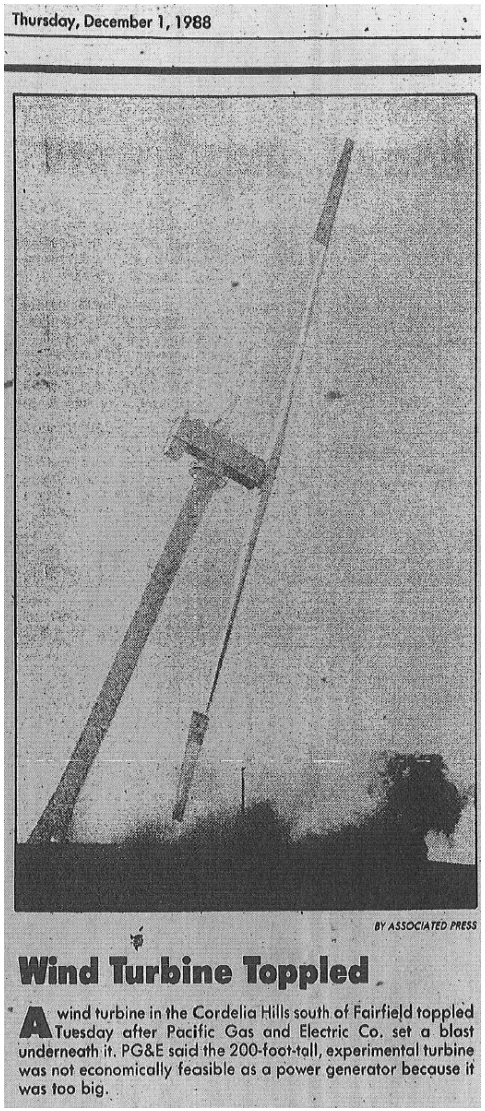
Reynolds number

$$\mathrm{Re} = \frac{\rho U_\infty L}{\mu}$$

Where:
ρ is the density
U_∞ is the velocity
L is a length
μ is viscosity

- Characterizes the flow regime
- Relative from high to low
  - Supersonic jets
  - Passenger jet aircraft
  - Light aircraft
  - Wind turbines
  - Human powered aircraft
  - Insect flight
  - Molasses from a jar

My PG&E MOD experience



Thursday, December 1, 1988

BY ASSOCIATED PRESS

Wind Turbine Toppled

A wind turbine in the Cordelia Hills south of Fairfield toppled Tuesday after Pacific Gas and Electric Co. set a blast underneath it. PG&E said the 200-foot-tall, experimental turbine was not economically feasible as a power generator because it was too big.

Career beginnings

- Graduated Dec 1988
  - 80's Soviet Glasnost
  - 1989 Berlin Wall Falls
- NASA Ames Research Center
  - 1989-1990 Space Life Sciences
  - 1990-1995 Full-Scale Aerodynamics
  - Interest in rotor dynamics
  - Stanford M.S. 1993
  - Aching to work in wind energy

Spacelab in Shuttle Bay
NASA Photo

SECOND GENERATION

Transition to wind energy

- Left NASA for Kenetech Windpower
  - Are you crazy?
  - 1995-1996
- National Renewable Energy Laboratory
  - 1997-2001

Netherlands 1995

Back at NASA with NREL, 2000

Kenetech

American turbines on the
North Sea dike

Not around anymore…

Two-bladed

Downwind rotor

Lattice tower

Vertical axis

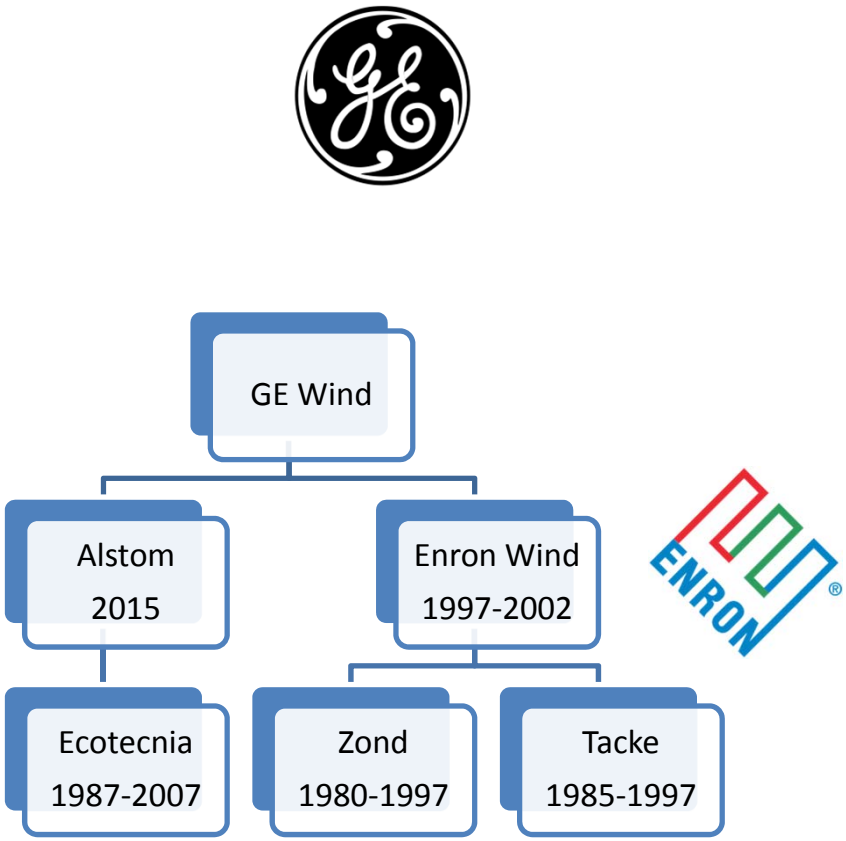
NREL photos

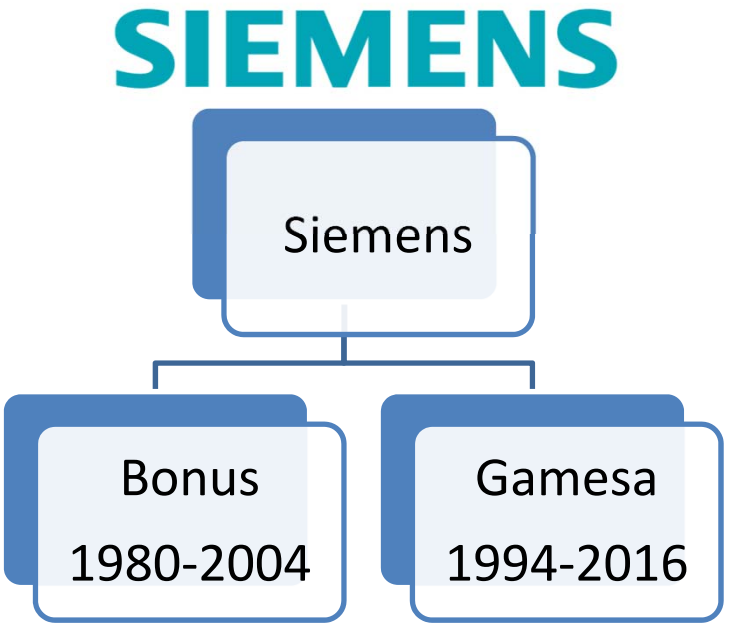
Avian deaths

- The Altamont- wind energy's big black eye
- Impact on the wind industry
- Assessment, mitigation, post-monitoring

THIRD GENERATION

Big Players


GE Wind
Alstom
2015
Enron Wind
1997-2002
Ecotecnia
1987-2007
Zond
1980-1997
Tacke
1985-1997

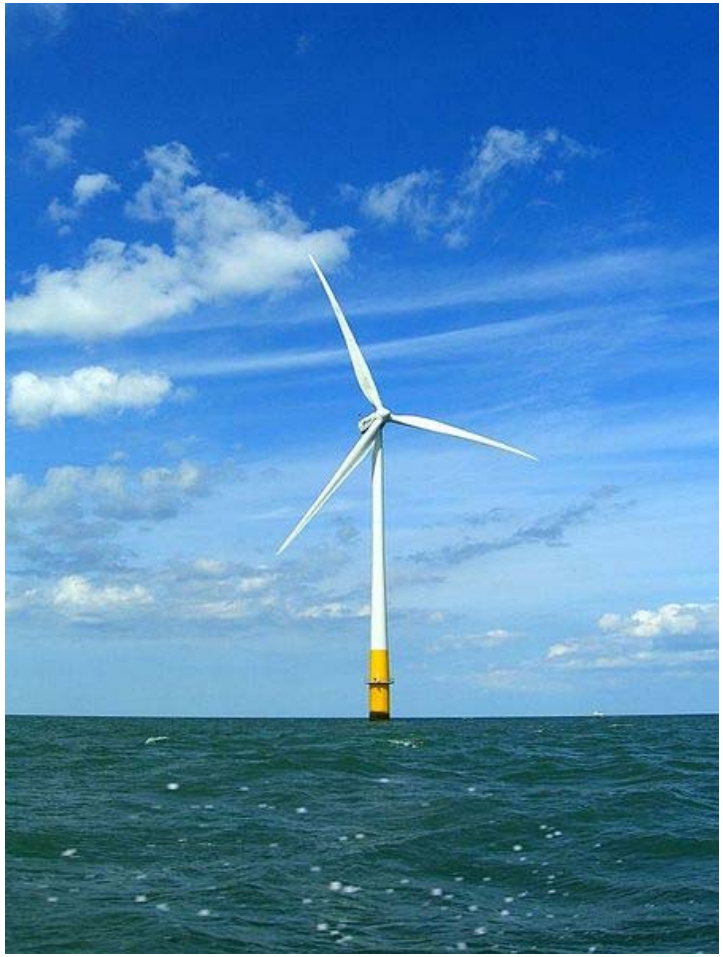

SIEMENS
Siemens
Bonus
1980-2004
Gamesa
1994-2016

My times and Enron/GE Wind

GE

Offshore Wind Energy

- 12 GW worldwide at end of 2015 (Wiser 2011)
  - Fastest growing market segment
- Majority in Europe, one plant in US
- Huge European projects in the pipeline
- A few potential East Coast projects on life support

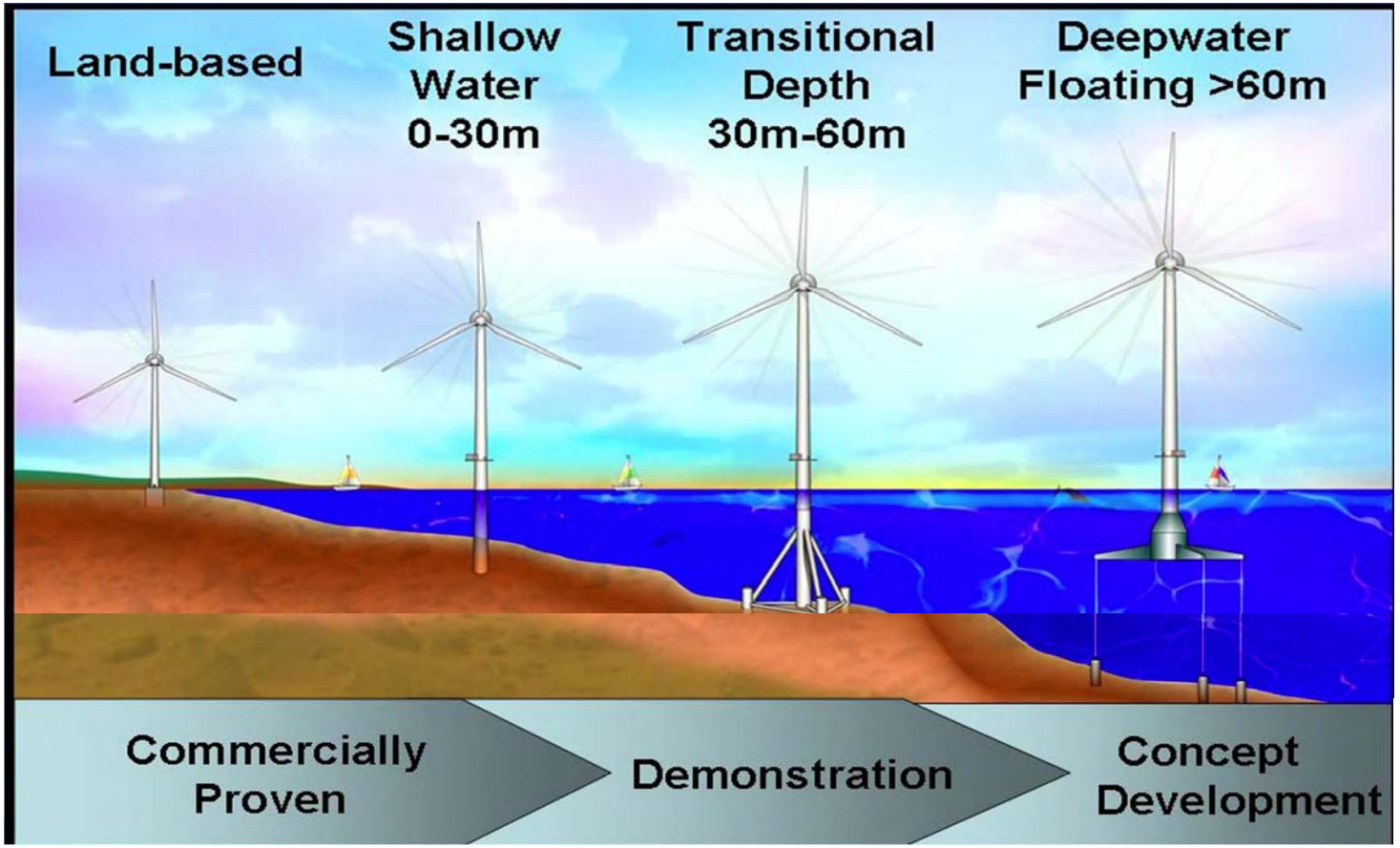


Wikipedia

America's First

Deepwater Wind

Primary Offshore Component



NREL

Benefits/Risks of Offshore Wind

- Benefits
  - Offshore winds more consistent and less turbulent
  - Creation of new industries and jobs
  - Revitalization of ports and harbors
- Risks
  - Use conflicts (e.g. cargo transport, fishing, recreation)
  - Wildlife conflicts (e.g. marine animal and birds)
  - Huge up front financial risk (e.g. permitting through several agencies)

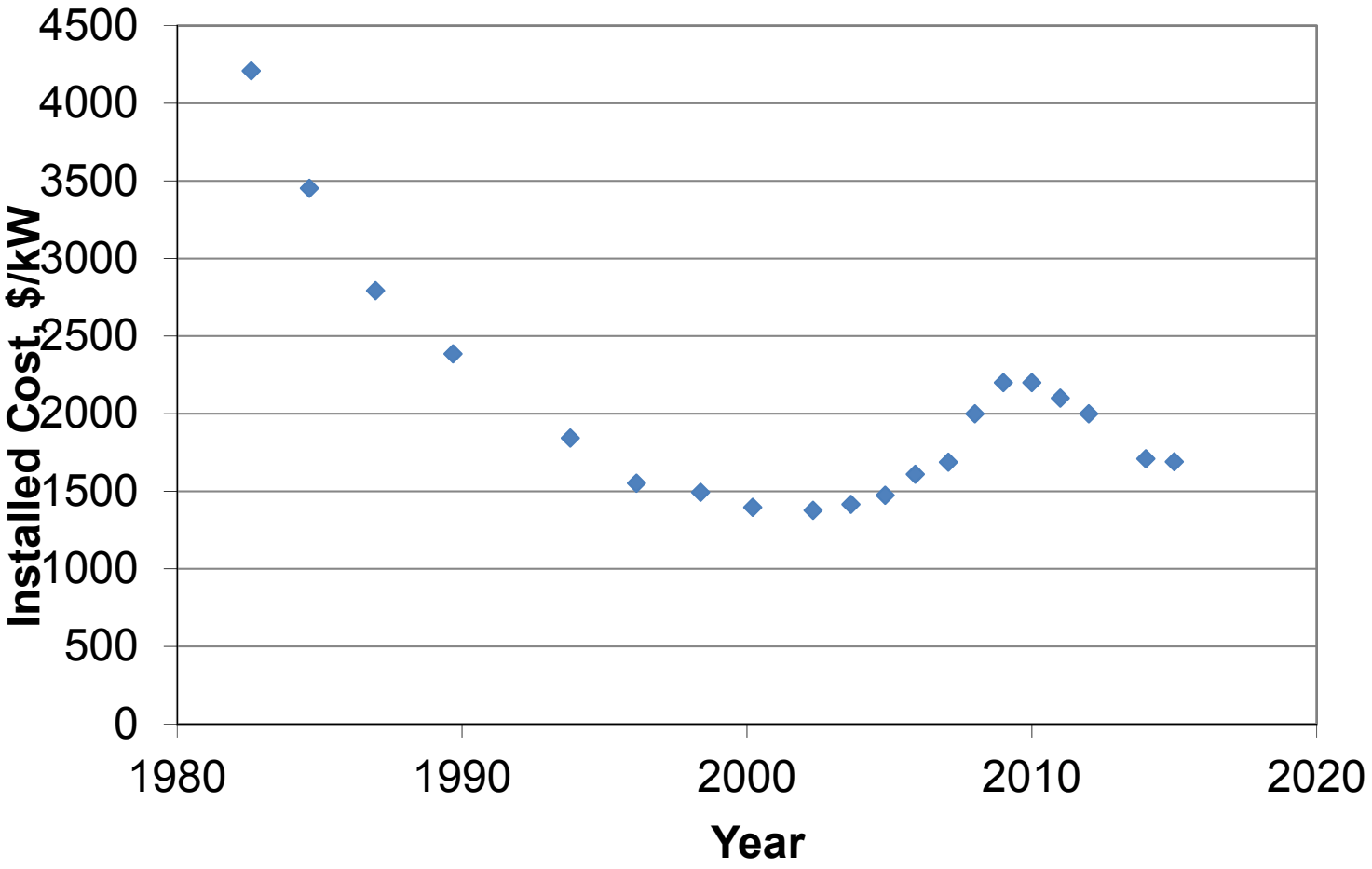
Wind energy approval index

- pollev.com/purlwind

"Technology does not develop by itself"

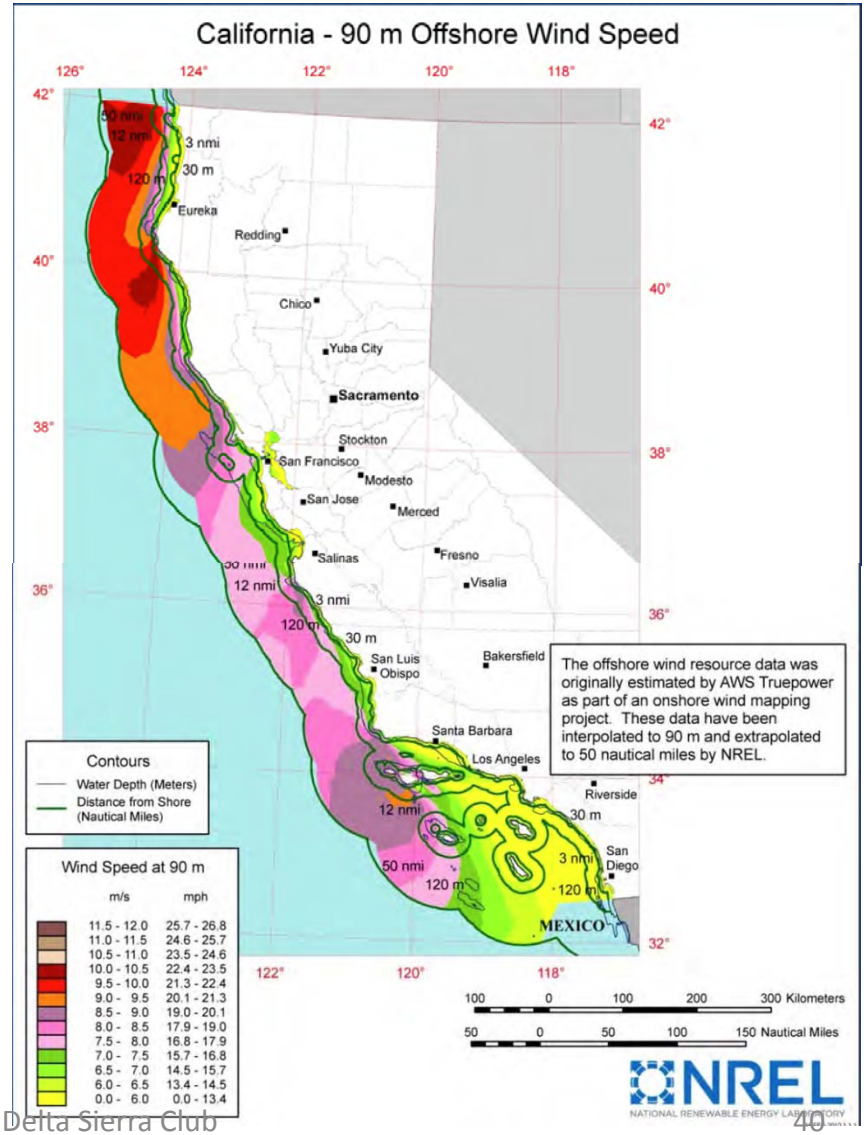
THE FUTURE

Cost Trends

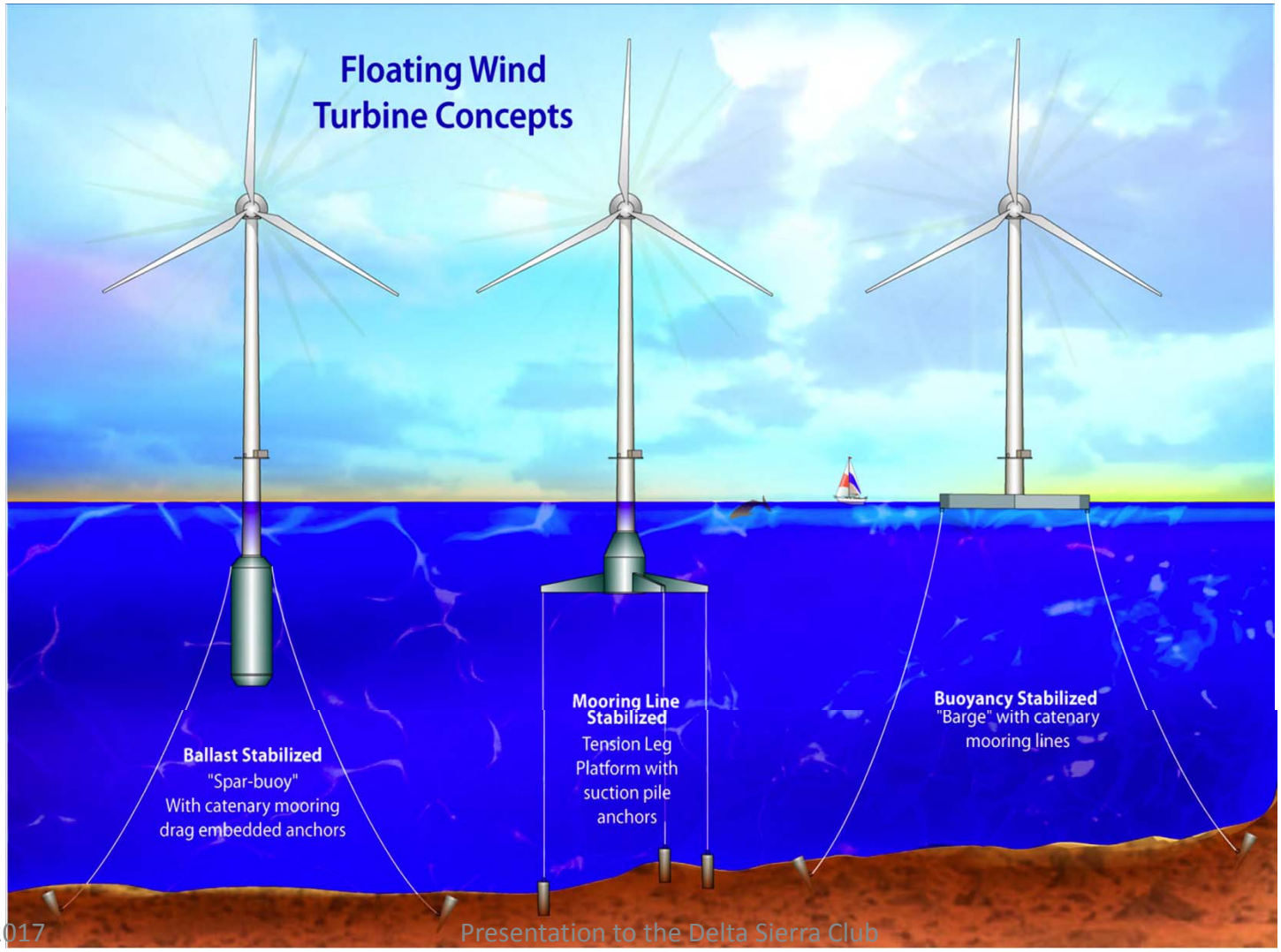

4500
4000
3500
3000
2500
2000
1500
1000
500
0
Installed Cost, $/kW
1980
1990
2000
2010
2020
Year

The California Offshore Resource

- Potential resources (Dvorak 2009)
  - Shallow water ~2 GW
  - Transitional water ~8 GW
  - Deepwater ~65 GW (compare 70 GW CA capacity)
- Offshore wind in California will most likely have to be deepwater
- Best resource in North Coast



Deepwater Technology



Will California go offshore?

- In the state of Maine:
  - 2010 State Legislation stating goals for 300 MW offshore power by 2020, 5000 MW by 2030
  - RFP for 30 MW floating demonstration project (Statoil responded)
  - University of Maine DeepCWind Consortium
- In the Golden State
  - Was the spark for the wind energy boom in the 1980s
  - No legislation, no funding, no commitment to offshore wind

Progress on Environmental Impacts

- Eagles/Bats/Grouse
- Detection, mitigation, deterrence
- E.g. radar detection

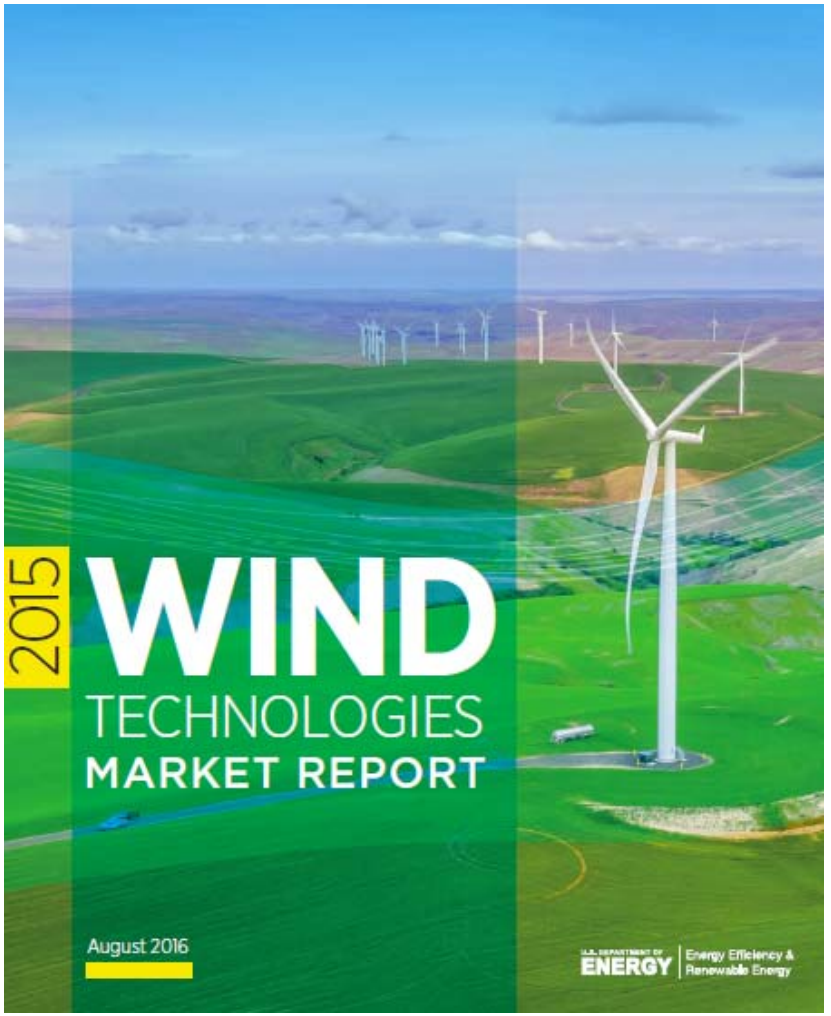
Golden Eagle at NWTC. Photo by John De La Rosa-Dennis Schroeder, NREL 35801

Integration with other renewables

- Storage needed for wind > 30% in CA
- Progress on storage
  - Electric vehicle fleet
  - Solar development in Southwest
- Diversity of resource big advantage

Back to the present

Swept blades- my dissertation topic



Closing Thoughts

- I am the fortunate son
- Wind turbines are more fun
- What to do with an aerospace degree

Questions?

- Thank you for inviting me.